

CHAPTER 7

CONSTRUCTION CONTROL

7-1. General. The heterogeneous nature of soil makes it the most variable construction material with which engineers are required to work. Research in soil mechanics and experience gained recently in constructing large earth embankments have provided additional knowledge toward understanding and predicting the behavior of a soil as a construction material. However, only with careful control can engineers ensure that backfill construction will satisfactorily fulfill the intended functions. Both the contractor and the Government share dual responsibility in achieving a satisfactory product. The contractor is responsible for inspection and tests through his quality control system. The Government's responsibility is assuring that the contractor's quality control system is achieving the desired results through its quality acceptance system.

a. Contractor quality control. The contractor is responsible for all of the activities that are necessary to ensure that the finished work complies with the plans and specifications to include quality control requirements, supervision, inspection, and testing. The construction contract special provisions explain the quality control system that the contractor must establish; the technical provisions specify the construction requirements with the tests, inspections, and submittals that the contractor must follow to produce acceptable work.

(1) Prior to construction, the contractor must submit for approval by the Contracting Officer his plan for controlling construction quality. The plan must contain all of the elements outlined in the special provisions and demonstrate a capability for controlling all of the construction operations specified in the technical provisions. The plan must include the personnel (whether contractor's personnel or outside private firm) and procedures the contractor intends to use for controlling quality, instructions and authority he is giving his personnel, and the report form he will use. The plan should be coordinated with his project construction schedule.

(2) During construction, the contractor is responsible for exercising day by day construction quality control in consonance with his accepted control plan. He must maintain current records of his quality control operations. Reports of his operations must be submitted at specified intervals and be in sufficient detail to identify each specific test.

(3) The prime contractor is responsible for the quality control of all work including any work by subcontractors.

b. Corps acceptance control. In contrast to the contractor's quality control, the Government is responsible for quality assurance, which includes: the checks, inspections, and tests of the products that comprise the construction; the processes used in the work; and the finished work for the purpose of determining whether the contractor's quality control is effective and he is meeting the requirements of the contract. These activities are to assure that defective work or materials are not incorporated in the construction.

c. Coordination between Government and contractor. The contractor's quality control does not relieve the Contracting Officer from his responsibility for safeguarding the Government's interest. The quality assurance inspections and tests made by the Government may be carried out at the same time and adjacent to the contractor's quality control operations. Quality control and quality assurance supplement one another and assist in avoidance of construction deficiencies or in early detection of such deficiencies when they can be easily corrected without requiring later costly tear out and rebuild. The remainder of this chapter discusses the Corps quality assurance activities.

7-2. Corps acceptance control organization.

a. General. Difficulties in construction of a compacted backfill can be attributed at least in part to inexperience of the control personnel in this phase of construction work or lack of emphasis as to the importance of proper procedure and control. Since it is essential that policies with regard to control be established prior to the initiation of construction, thorough knowledge of the capabilities of the control organization and of the intent of the plans and specifications is required. Control is achieved by a review of construction plans and specifications, visual inspection of construction operations and procedures, and physical testing. A well-organized, experienced inspection force can mean the difference between a good job and a poor one. A good field inspection organization must be staffed and organized so that inspection personnel and laboratory technicians are on the job when and where they are needed. Thus the organization must have knowledge of the construction at all times.

b. Inspection personnel training program. Prior to construction, the training, guidance, and support required to ensure that the inspection force is fully competent should be determined. If experience is lacking, training and supervision become more important and necessary.

(1) The training program for earthwork inspection personnel should consist of both classroom and field instruction. During the classroom sessions, the specifications should be studied, discussed, and interpreted as to the intent of the designer. The critical areas of compaction should be pointed out as well as the location of zoned and transitional areas. The inspection personnel should be instructed on the various zones of backfill, types of backfill, density requirements, and classification and compaction characteristics for each class of backfill. Inspection personnel should also be instructed as to approved sources of borrow for each type of backfill and borrow pit operations, such as loading procedures to provide uniform materials and pre-wetting to provide uniform moisture.

The various types of backfill should be studied, so inspection personnel can recognize and readily identify these materials. Jar samples may be furnished for later reference and comparison; preferably these should be samples of the particular soils on which laboratory compaction tests were performed in design studies. Instructions should be given as to water content control, lift thickness, and most suitable compaction equipment for each type of backfill. Inspection personnel should be capable of recommending alternate procedures to achieve the desired results when the contractor's procedure is unsuccessful.

(2) Inspection personnel should be made aware of the importance of their work by explaining the engineering features of the design on which the construction requirements are based. Every opportunity should be taken to assemble the inspection force for discussion of construction problems and procedures so that all can gain knowledge from the experience of others. Inspection personnel should be kept informed of all decisions and agreements pertinent to their work that are made at higher levels of administration. They should be advised of the limits of their authority and contact with contractor personnel.

(3) Field training of inspection personnel should include observation of their control techniques and additional instruction on elements of fieldwork requiring correction. Inspection personnel should be instructed in the telltale signs that give visual indications whether sufficient compaction is being applied and proper water content is being maintained (see para 7-5b (4) and EM 1110-2-1911 for discussion of telltale signs). They should develop the ability to determine from visual observations (based on correlations with tests on the project) that satisfactory compaction is being obtained so

that considerable emphasis can be placed on such methods as a control procedure rather than relying on field tests alone. Inspection personnel should be capable of selecting locations at which field density and moisture determinations should be made. To meet this requirement they must be present almost continuously during compaction operations to observe and note areas where tests appear to be needed. Laboratory technicians should be made available to perform tests so that the inspection personnel will be free to observe the placement and compaction process on another portion of the backfill. Inspection personnel should be able to use expedient quick-check field apparatus such as the Proctor and hand-cone penetrometers (sec. B-3, app. B) to make a rapid check of the field water content to supplement acceptance testing and to serve as a guide in determining areas that should be tested. Inspection personnel should also be well versed in normal testing procedures so they can properly supervise testing or explain the procedure in case they are questioned by contractor personnel.

(4) It is necessary and important that inspection personnel ascertain their authority and responsibility at an early stage in the construction. Their policy should be one of firmness coupled with practicality. The quality of the work should not be compromised; however, unreasonable requirements and restrictions should not be placed on the contractor in enforcing the specifications. If the inspection personnel know their job and are fair and cooperative in dealing with the contractor, they will gain his or her respect and cooperation and be able to efficiently carry out their responsibilities.

b. *Field laboratory facilities.* The field laboratory is used for routine testing of construction materials (such as gradation, water content, compaction, and Atterberg limits tests) and for determining the adequacy of field compaction. The data obtained from tests performed by inspection personnel serve as a basis for determining and ensuring compliance with the specifications, for obtaining the maximum benefit from the materials being used, and for providing a complete record of the materials placed in every part of the project. The size and type of laboratory required are dependent on the magnitude of the job and the type of structures being built. Where excavation and backfill construction are extensive and widespread, the establishment of a centrally located field laboratory is generally beneficial. This laboratory in addition to having equipment for on-the-job control will provide a nucleus of experienced soils engineers or engineering technicians for general supervision and training of inspection personnel. Field control laboratories on the sites may be established as necessary during the excavation and backfill phases of the construction. They may be set up

in an enclosed space allocated by the project officer or in mobile testing laboratories, such as pickup trucks with a camper and equipped with the necessary testing equipment for performance of field density tests, water content tests, and gradation tests. Another possibility is the use of large portable boxes in which equipment is stored. When special problems arise and the required testing equipment is not available at the site laboratory, the testing should be performed at the central laboratory.

7-3. Excavation control techniques. Control to obtain a satisfactory excavation is exercised by enforcement of approved plans, visual observations, a thorough knowledge of the contractor's plan of operation and construction schedule, the dimensions and engineering features of the structure(s) to be placed in the excavation, and vertical and horizontal control measurements to ensure that the proper line and grade requirements are met.

7-4. Foundation preparation control techniques. The main control technique for ensuring proper foundation preparation is visual inspection.

Prior to backfill placement, all uncompacted fill should be removed from those portions of the excavation to be backfilled. The items included are road fills, loose material that has fallen into overexcavated areas adjacent to foundations, and construction ramps other than those required for access to the excavation. Identification of such items will be easier if the inspection personnel have charted the items on the plans as they were created, since they are not always easily discernible by visual inspection. It is desirable to control earth backfill placed in foundation leveling operations by water content and density tests. Care should be exercised to ensure that all subdrains required in the foundation are protected by filters and transitional zones that are adequate to prevent infiltration of fines from the surrounding backfill that might otherwise clog the drains and undermine structures.

7-5. Backfill quality acceptance control.

The necessary authority to assure that compacted backfill is in compliance with the specifications is given in the specifications. The control consists of inspecting and testing materials to be used, checking the amount and uniformity of soil water content, maintaining the proper thickness of the lifts being placed, and determining the dry unit weight being obtained by the compaction process. While control consists of all of these things, good inspection involves much more.

a. Inspection activities. One of the best inducements to proper placement and compaction of backfill is the presence of the inspection personnel when backfill is being placed. However, to be of value the inspector must know his job. He should be familiar with

all aspects of backfill operation, such as selection and availability of materials, processing, hauling, compaction, and inspection procedures. Some of the most common deficiencies in inspection personnel activities are as follows:

(1) Failing to enforce specification requirements for preparation of the area for backfill. Often temporary fills, the working platform, debris, and other undesirable materials are left in the excavation causing weak areas and resulting in greater consolidation in the backfill.

(2) Failing to be cognizant of detailed site-adapted plans for stockpiling and placing backfill at specific locations. Without knowledge of these plans, inspection personnel are sometimes forced to make engineering decisions beyond their capability, such as on-the-site approval of a new material or mixture of materials, and stockpile locations.

(3) Allowing processing of backfill material and adjustment of water content on the fill that should have been accomplished prior to placement. The results are the segregation of grain sizes and the non-uniform distribution of water content. All major processing, including crushing, raking, mixing, and adjusting of water content, must be done in the stockpile or borrow areas.

(4) Allowing lift thickness that is inconsistent with equipment capabilities and thicker than that allowed by specifications. Field density determinations will not necessarily detect this inconsistency.

(5) Allowing construction of backfill slopes that are too steep to obtain the full effect of compaction equipment.

(6) Failing to require that the fill be built up uniformly in a well-defined pattern. Since the contractor's next move cannot be predicted, the inspection personnel cannot adequately plan their operations, and it is difficult to determine which areas of backfill have been tested and approved when the backfill is built up in an unorganized manner.

(7) Allowing segregation of coarse-grained, non-cohesive materials. This condition is caused by improper hauling, dumping, and spreading techniques.

(8) Allowing the use of compaction equipment not suited to material being compacted.

(9) Failing to perform sufficient field density testing in critical areas.

(10) Allowing material that is too wet or too dry to be compacted.

(11) Failing to require that intermediate backfill surfaces be shaped to drain during backfilling at other locations.

b. Inspection requirements. To properly control and inspect backfill operations, the inspection personnel must keep informed of the construction schedule at all times and be at the site where backfill is being placed.

The inspection personnel must be thoroughly familiar with every aspect of the earthwork section of the specifications and know boundary locations for the various zones of material. They should be able to readily identify the various classes of backfill and know their compaction characteristics and requirements.

Good inspection personnel will also know the compaction capabilities of various types of equipment and the materials that each type is best suited to compact.

(1) To maintain adequate control of compaction operations, a staff of earthwork inspectors and laboratory personnel commensurate with the importance of the work and size of the operation is essential. There should be at least one inspector at the fill when backfill is being placed. His sole duty should be inspection of earthwork. Although he should be familiar with the testing procedures and capable of directing testing operations and selecting locations for testing, he should not be required to perform the tests. Laboratory technicians should be available for this purpose. A discussion of the methods and procedures for field density testing of the compacted fill is contained in section B-3, appendix B.

(2) The specifications should require that necessary processing of backfill materials be performed in the stockpile or borrow pit. Processing includes raking or crushing to remove oversize material, mixing to provide uniformity, and watering or aerating to attain a water content approximating optimum for compaction. An earthwork inspector is required at the stockpile or borrow pit to enforce these provisions. In addition, this inspector has the duties of classifying the materials, determining their suitability, and directing the zone of backfill in which they are to be placed. He is charged with the responsibility of seeing that the contractor uses the materials available for backfill in the most advantageous manner. Generally, the stockpile or borrow pit inspector relies upon visual inspection and experience to exercise control over these operations. Occasionally, he may require that appropriate tests be performed to confirm his judgment.

(3) The duties of the backfill inspector consist of checking the material for suitability as it is placed on the fill and spread, ensuring that any oversize material, roots, or trash found in the material is removed, checking the thickness of the lift prior to compaction, checking for uniformity and amount of water content, observing compaction operations, and directing or monitoring testing of the compacted material for compliance with density and water content requirements.

(4) There are many techniques and rule-of-thumb procedures that the earthwork inspector can and must resort to for assistance in his work. A few of them are discussed below; others can be ascertained by

inspectors meeting together to discuss problems and corrective action.

(a) The thickness of loose lifts can be checked easily by probing with a calibrated rod just prior to compaction. Compaction of lifts too thick for the equipment will not normally be detected by performing density tests on the lift, since adequate compaction may be indicated by a test made in the upper portion of the lift and the lower portion may still have too low a density. It is therefore a requisite that lift thickness be controlled on a loose-thickness basis prior to compaction.

(b) Checks for proper bond between layers can be made by digging through a lift after compaction and using a shovel to check this bond. If the soil can be separated easily along the plane between lifts, sufficient bond is not being provided. Backfill materials should not be placed on dried or smooth surfaces, as bond will be difficult to obtain.

(c) Inspection personnel should be thoroughly aware of areas where compaction is critical. These areas are the confined spaces around and adjacent to structures that are not accessible to the rolling and spreading equipment. Although the volume of backfill is usually rather small in these areas, a much higher frequency of check testing for density is required as well as a careful check of the quality and water content of the materials to be placed.

c. Compaction control tests. Compaction tests will have been performed on representative specimens obtained from exploratory sampling prior to construction. The selection of suitable backfill material are in fact generally made based on these and other tests. At least during the early phases of the backfill operation, density requirements are based on these and in some cases additional preconstruction compaction tests. Conditions may develop that require compaction tests during backfill operations to establish new density requirements. Generally, these changes are the results of backfill material deviations. The need for additional control tests may be ascertained from visual observation and changes in compaction characteristics during field compaction. For most backfill materials, quality acceptance compaction control tests must be performed according to the CE 55 test procedure specified in MIL-STD-621, the equivalent procedure in ASTM D 1557, or the two-point test procedure (app B). For some cohesionless soils where higher maximum dry densities can be obtained using the vibratory (relative density) compaction procedure, the specifications may require the vibratory test procedures as specified in EM 1110-2-1906 or ASTM D 2049. Field compaction control and rapid compaction check tests that are used to supplement the Corps acceptance control tests are discussed in appendix B.

d. Field moisture-density control techniques. Moisture-density control is the most important phase of

backfill operations. The success of ensuring required backfill density often determines the functional service of the imbedded structure. Good control involves many techniques. An experienced inspector will not rely on any one technique but from experience will base his control on a combination of techniques. Moisture-density control techniques may be grouped into three categories: rule-of-thumb techniques, and indirect and direct moisture density measurements.

(1) *Rule-of-thumb methods.* Rule-of-thumb techniques are derived from experience and are based on visual observations and feel of the material. A rule-of-thumb for judging if the water content of a fine grained, plastic material is near the optimum water content consists of rolling the material between the hands until it forms a thread approximately $\frac{1}{8}$ inch in diameter. If the material at this stage tends to crack or crumble, it is in the proper water content range for compaction. It will be recognized that this method is similar to the method of determining the plastic limit of a soil. The methods are similar because the optimum water content for compaction of a cohesive soil roughly approximates the plastic limit of the soil.

(a) Another good indication of whether the proper water content has been obtained can be determined by observing the compacting equipment. When a sheepsfoot roller is being used and the soil sticks to the roller to any great extent, the material is being rolled too wet for the equipment being used; at optimum water content it may be expected that a few clods will be picked up by the roller but a general sticking will not occur. If the compacted fill does not definitely spring (noticeable to visual observation) under hauling and compaction equipment, it is probable that several lifts of fill have been placed too dry. The roller should roll evenly over the surface of the backfill if water content is uniform throughout the lift and should not ride higher on some portions of the backfill than on others. If on the first pass of a rubber-tired roller the tires sink to a depth equal to or greater than one half the tire width, if after several passes the soil is rutting excessively, or if at any time during rolling the weaving or undulating (as opposed to normal "springing" of the surface) of the material is taking place ahead of the roller, either the tire pressure is too high or the water content of the material is too high. On the other hand, if the roller tracks only very slightly or not at all and leaves the surface hard and stiff after several passes, the soil is probably too dry. For most soils having proper water contents, the roller will track evenly on the first pass and the wheels will embed 3 to 4 inches. Some penetration should be made into soil at its proper water content, though the penetration will decrease as the number of passes increases. After several passes of a sheepsfoot roller, the roller should start walking out if adequate and efficient compaction is being obtained. Walking out means the roller begins bearing on the soil through its feet only-the drum is riding

a few inches above the soil surface. If the roller walks out after only a few passes, the soil is probably too dry; if it does not walk out but continues churning up the material after the desired number of passes, the soil is too wet or the foot contact pressure is too high.

(b) A trained inspector will spend some time in the field laboratory, performing several compaction tests on each type of backfill material to become familiar with the differences in looks, feel, and behavior and learning to recognize when they are too dry or too wet, as well as when they are at optimum water content.

(2) *Indirect methods.* Indirect methods of determining the density and water content involve measurement of the characteristic of the material that has been previously correlated to the maximum density and optimum water content. These methods of measuring in-place density and water content can usually effect a more detailed control of a job than can be accomplished by direct methods alone because they can provide quicker determinations. However, no indirect method should ever be used without first checking and calibrating it with results obtained from direct methods, and periodic checks by direct methods should be made during construction. Indirect methods include the use of the nuclear moisture-density meter, the Proctor penetrometer (often referred to as the "Proctor needle"), the hand cone penetrometer, and in the hands of an experienced inspector even a shovel.

(a) The nuclear moisture-density method conducted in accordance with ASTM D 2922 (for density determination) and ASTM D 3017 (for water content determination) is the only indirect control method used for the Corps quality acceptance control. The method provides a relatively rapid means for determining both moisture content and density. Of the three methods presented in ASTM D 2922, Method B - Direct Transmission is the best suited for a compacted lift thickness exceeding approximately 4 inches. The nuclear moisture-density method is discussed in more detail in section B-3, appendix B.

(b) Penetrometers, such as the Proctor and hand cone penetrometers, are useful under certain conditions for approximating density. However, both methods require careful calibration using soils of known density and water content and considerable operating experience. Even then, the results may be questionable because non-uniform water content (in fine-grained material) or a small piece of gravel can affect the penetration resistance. Penetrometers, therefore, are not recommended for general use in compaction control; however, they can be a very useful tool in supplementing the inspector's visual observations and providing a general guide for detecting areas of doubtful compac

tion. The procedure using the Proctor penetrometer for determining the relation between wet density, penetration resistance, and water content is described in ASTM D 1558 and in section B-3, appendix B. The hand cone penetrometer procedure also is discussed in section B-3.

(c) Many inspectors in the past have had good success in estimating density by simply observing the resistance of the compacted soil to penetration by a spade. This method requires considerable experience and is useful only in detecting areas that might require further density tests.

(3) Direct methods. Direct field density determination consists of volume and weight measurements to determine the wet density of in-place backfill and water content measurements to determine in-place water contents and dry densities. The three methods used for the Corps quality acceptance density determination are: (a) the sand-cone method according to MIL-STD-621 (Method 106) and ASTM D 1556; (b) the rubber-balloon method according to ASTM D 2167; and for soft, fine-grained cohesive soils, the drive-cylinder method according to MIL-STD-621 (Method 102) and ASTM D 2937. In addition to the approved methods, a method sometimes employed to measure densities of coarse-grained cohesionless material consists of the large-scale, water-displacement method. The large-scale, water-displacement method is discussed in EM 1110-2-1911. The sand cone method is considered to be the most reliable method and is recommended as the proof or calibration test for calibrating other methods such as the nuclear density method. The direct field density methods are discussed in section B-3, appendix B.

e. Water content by microwave oven. The biggest problem associated with both field compaction tests and in-place density and water content control tests is the length of time required to determine water content. Conventional overdrying methods require from 15 to 16 hours for most fine-grained cohesive soils. In some cases, such as confined zones, the contractor may have placed and compacted several layers of backfill over the layer for which density tests were made before quality acceptance test data are available. Even though the contractor places successive layers at his own risk, a rapid turn around between testing and test results could prevent costly-tear out and recompact procedures. Drying specimens in microwave ovens offers a practical means for rapid determination of water content for most backfill materials if properly conducted. Times required for drying in a microwave oven are primarily governed by the mass of water present in the specimen and the power-load output of the oven. Therefore, drying time must be calibrated with respect to water content and oven output. Also, it may not be possible to successfully dry certain soils containing gypsum or highly metallic soils such as iron ore, aluminum rich soils, and bauxite.

Details of the microwave-oven method used for rapid determination of soil water content is given in section B-3, appendix B.

f. Frequency and location of quality acceptance density tests. Acceptance control testing should be more frequent at the start of backfill placement. After compaction effort requirements have been firmly established and inspection personnel have become familiar with materials behavior and acceptable compaction procedures, the amount of testing can be reduced. Many factors influence the frequency and location of tests. The frequency will be dependent on the type of material, adequacy of the compaction procedures, and how critical the backfill being compacted is in relation to the performance of the structure.

(1) A systematic testing program should be established at the beginning of the job. Acceptance control tests laid out in a predetermined manner are usually designated as routine control tests and are performed either at designated locations or at random representative locations, no matter how smoothly the compaction operations are being carried out. A routine acceptance control test should be conducted for at least every 200 cubic yards of compacted backfill material in critical areas where settlement of backfill may lead to structural distress and for at least every 500 cubic yards in open areas not adjacent to structures.

(2) In addition to routine acceptance control tests, tests should be made in the following areas: where the inspector has reason to doubt the adequacy of the compaction; where the contractor is concentrating fill operations over relatively small areas; where small compaction equipment is being used such as in confined areas; and where field instrumentation is installed, mainly around riser pipes.

g. Errors in field density measurements. Density and water content measurements determined by any of the methods discussed above are subject to three possible sources of errors. The three categories of possible error sources are human errors, errors associated with equipment and method, and errors attributed to material property behavior.

(1) Human error includes such factors as improper equipment readings and following improper test procedures. Human errors are not quantitative. However, errors of this type may be minimized by utilizing competent testing personnel familiar with testing procedures.

(2) There are two types of possible errors related to test equipment. One type of error relates to the sensitivity of the equipment with respect to its capability to accurately measure the true density or water content. Sensitivity errors are quantitative only in the sense that limiting ranges of possible error can be es

tablished. An example of sensitivity error would be the nuclear density device that is capable of determining densities only to within 3 to 5 pounds per cubic foot of the true density. The second type of error relates to constant deviations between measured and true density. Constant deviation errors can be corrected by calibrating test equipment against known densities.

(3) Material property errors are primarily limited to density determinations using either the sand-cone or the rubber-balloon method in sands. When a soil is physically sampled during the process of conducting an in-place density measurement using these two methods, a shearing action of the soil is unavoidable. Cohesionless soils are sensitive to volume change during shear, dense sands tend to expand and increase in volume, and loose sands tend to contract and decrease in volume. Errors of this nature cannot be quantified or detected in the field. However, such errors can be as high as 6 percent for sand using the rubber-balloon method for volume measurements.

h. Acceptance or rejection. The inspection personnel have the responsibility to accept or reject the backfill or any part thereof based on the quality acceptance control tests. On the surface, this task seems straightforward. If a segment of the backfill tested at several locations for acceptance passes or fails to pass minimum requirements by a wide margin, then it is generally safe to assume that the backfill within that segment either has or has not been adequately compacted and the acceptance or rejection of that segment can be made based on the test results. On the other hand, if the tests indicated insufficient compaction, the size of the affected area may be questionable; it is possible that the test(s) represents only a small area and the lift being tested may be sufficiently compacted elsewhere. In view of the possible errors associated with control tests, tests that indicate marginal passage or failure should be treated with caution. The borderline case requires a close look at several factors: how the result compares with all previous results on the job, how much compaction effort was used and did it differ from previous efforts, how does this particular material compare with previously compacted materials, the importance of the lift location in relation to the entire structure, and the importance of obtaining the correct density or water content from the designer's standpoint. When all factors have been considered, a decision is made as to which corrective measures are required. What makes such decisions so difficult is that they must be made immediately; time will not permit the problem to be pondered. Discussion with design engineers prior to beginning compaction operations may help in the evaluation of many of these factors.

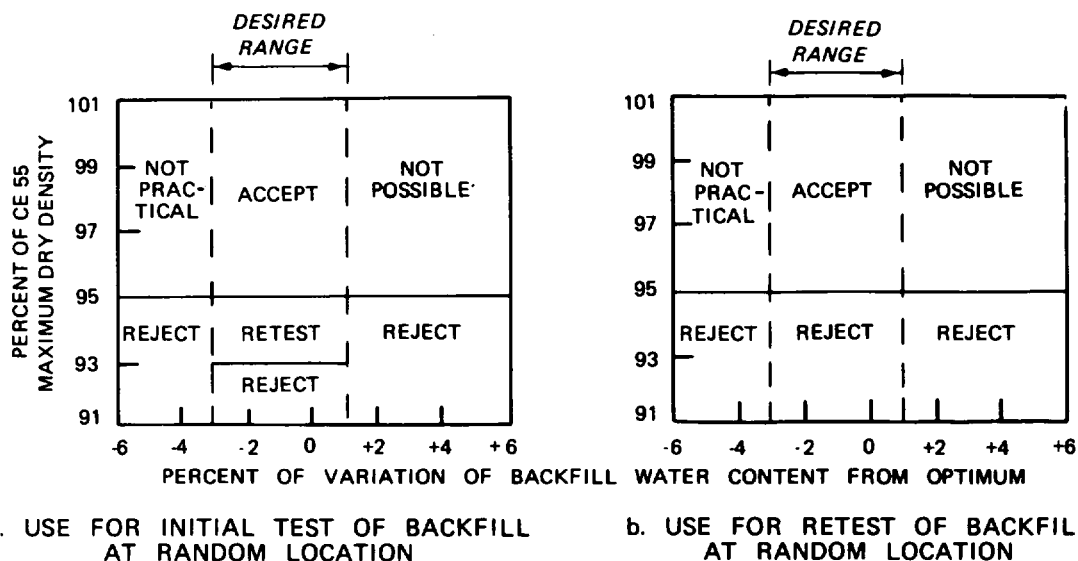
(1) On jobs requiring large volumes of backfill, it may be advantageous to base the decision to accept or reject on statistical methods. Statistical

methods require separate analysis for each backfill material type and compaction effort, complete random selection of test locations, and a large number of control tests as compared with the conventional decision method. In addition, statistical methods include water content control, which is not normally included in military specifications.

(2) The theory and details concerning the application of statistical methods for compaction control are well developed. Figure 7-1 shows a sequential inspection plan example of how the end results of a statistical analysis might be used for the purpose of acceptance or rejection. In this example, it was established by statistical analysis that adequate densities could probably be obtained with reasonable confidence by a given compaction effort for desired water contents ranging from 3 percentage points below to 1 percentage point above optimum. It was also established that a density corresponding to 95 percent of CE 55 maximum dry density was the minimum acceptable density based on required engineering performance of the backfill. The sequential inspection plan consists of examining, in sequence, single tests that are obtained at random from a segment of the backfill being considered for acceptance or rejection and, for each test, making one of three possible decisions: the segment is acceptable; the segment is unacceptable; and the evidence is not sufficient for either decision without too great a risk of error as indicated by the retest block in figure 7-1(a). The reject areas in figure 7-1 indicate conditions that cannot be corrected by additional rolling. The material must be replaced in thinner lifts and be within the desired water content range before adequate compaction can be achieved with the compaction equipment being used. If the retest decision is reached, an additional test is made at a second random location, and the same three decisions are reconsidered in light of this additional information. If the second test falls below the accept blocks, the segment of backfill representative of that test should be rejected; or if compaction procedures that have produced acceptable tests in the past have not been altered, then the compaction characteristics of that part of the backfill should be reevaluated.

(3) The primary advantage of statistical methods is that they offer a means of systematically evaluating acceptance or rejection decisions rather than leaving such decisions entirely to the judgment of the inspection personnel. However, if experienced and well trained inspection personnel are available, this approach may not be necessary.

i. Construction reports. A record should be maintained of construction operations. It is valuable in the event repairs or modifications of the structure are required at a later time. A record is necessary in the event claims are made either by the contractor or the



NOTE: 95=SPECIFIED MINIMUM ACCEPTABLE PERCENT OF CE 55 MAXIMUM DRY DENSITY

Figure 7-1. Acceptance Rejection Scheme for a Backfill Area.

Contracting Officer that work required or performed was not in accordance with the contract. Recorded data are also beneficial in improving knowledge and practices for future work. The basic documents of the construction record are the plans and specifications, modifications adopted that were considered to come within the terms of the contract, amendments to the contract such as extra work orders or orders for change, results of tests, and measurements of work performed. The amount of reporting required varies according to the importance and magnitude of the earthwork construction phase of the project and the degree of available engineering supervision. The forms to be used should be carefully planned in advance, and the inspection personnel should

be apprised of the importance of their reports and the need for thorough reporting. Records should be made on every test performed in the laboratory and in the field. All information necessary to clearly define the locations at which field tests are made should be presented. In the daily reports, inspection personnel should include information concerning progress, adequacy of the work performed, and retesting of areas requiring additional work to meet specifications. These daily reports could be of vital importance in subsequent actions. It is good practice for the inspection personnel to keep a daily diary in which are recorded the work area, work accomplished, test results, weather conditions, pertinent conversations with the contractor, and instructions received and given.